The decline of the Green and Golden Bell Frog *Litoria aurea* viewed in the context of declines and disappearances of other Australian frogs

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ABSTRACT

The Green and Golden Bell Frog *Litoria aurea* has undergone a reduction in range and significant population declines during the past 15 years. In this paper the decline is viewed from the perspective of declines and disappearances of other species of frog along the east coast of Australia. In contrast to *L. aurea* most declines affected species occurring at high altitude with relatively restricted ranges. These species typically bred in streams, adults were closely associated with stream habitats, and anthropogenic impacts such as habitat destruction, pollution or introduced predators have not been identified. The decline of the Green and Golden Bell Frog accords in part with this pattern, high altitude populations have disappeared and low altitude populations have declined. However, the habitat of adults and breeding sites are typically associated with ponds and swamps not streams. Because the causal agent responsible for declines has not been identified, an experimental approach is considered to be necessary to identify the causal agent, in addition to monitoring and field observations.

INTRODUCTION

Considerable attention has been devoted to the decline in abundance and number of populations of the Green and Golden Bell Frog *Litoria aurea* (Osborne *et al.* 1996; White and Pyke 1996; see also other papers in Pyke and Osborne 1996). Several remaining populations have been the subject of fauna surveys and Fauna Impact Statements (FISs) related to development applications that involve proposals for habitat modification (Cogger *et al.* 1993; Greer 1994). These have brought the plight of the species into the public arena and prompted a closer consideration of its conservation management across its range. The FISs, while focused on the impacts of the proposed development on the respective population, have also needed to address the question of why the species has disappeared from so many sites, but survived at other sites?

It is generally accepted that the conservation of threatened species involves identifying the threatening or potentially threatening processes, and acting to mitigate these. In the majority of cases declines in species can be related to deterministic causes, such as, habitat alteration, introduced predators or diseases, and pollution (Groombridge 1992; Ferraro and Burgin 1993). It is not surprising, therefore, in the case of the Green and Golden Bell Frog, that Fauna Impact Statements have considered maintenance of the habitat and preventing the introduction of potential predators, as primary goals. A range of habitat features associated with the species have been investigated, and habitat attributes necessary for the persistence of viable populations considered (see Pyke and White 1996), but it is evident that these attributes are not consistent across the range of the species (see Gillespie 1996). At the same time, a negative relationship between the presence of the frog and the introduced Mosquito Fish *Gambusia holbrooki* had been noted (Mahony 1993; Cogger 1993; Harris 1995; White and Pyke 1996). Successful management of these populations should be possible if the cause of the decline of the species can be identified and removed, and suitable habitat maintained. Persistence of the species at these sites implies that the habitat is suitable for the species, although long-term population studies have not been done to determine the demographics of these populations. In searching for the cause of the species decline, it is also important to take into account observations that relate to the decline of other species of frog in Australia.

The aim of this paper is to assess the decline of the Green and Golden Bell Frog *Litoria aurea* in the wider context of frog declines in Australia. For reviews of the extensive literature on amphibian declines worldwide, and the hypothesized causes for other reported declines and disappearances, readers are referred to recent reviews by Tyler (1991), Vial and Saylor (1993), and Blaustein and Wake (1990, 1994).

DISCUSSION

Populations Declines: Natural Fluctuations or Evidence of Deleterious Impacts?

A persistent argument raised in response to the current decline of amphibian populations is that we may be watching natural fluctuations that occur on a temporal and spatial scale that have not been previously recognized. Indeed in the early years when the Southern Gastric Brooding Frog *Rheobatrachus silus* of south-east Queensland did not appear for several seasons, herpetologists proposed that this was due to climatic factors such as drought, and they assumed the species would reappear when conditions were more suitable (Chezura and Ingram 1990; Chezura 1991a, 1991b; Tyler 1983). Criticisms that surveys were not extensive enough and had not covered all likely habitats (unsuitability of spatial scale) can be dismissed. Surveys have covered most potential sites and have involved experienced herpetologists (Covecavich and McDonald 1993; Trennery *et al.* 1994). It is now apparent that the reported disappearances are real. Fifteen years has past since the Southern Gastric Brooding Frog disappeared. If the population of this species is operating on a fluctuating time scale, then the time frame is much greater than known for any amphibian. It is now apparent that some threatening process, not natural population fluctuations, are responsible for the disappearances/declines observed.

Assessing the current status of frog species along the east coast of Australia, to obtain a reliable picture of those species which are in decline and those which are not, poses a number of problems. There are over 110 species that occur in this area, which here is defined as the east coast and adjacent ranges. These species display a variety of distribution patterns. Surveys conducted on suitable temporal and spatial scales to enable a valid statement concerning the status of all species have not been possible. However, with the combined effort of numerous workers a picture does emerge of the population trends for most species. Closest attention has been placed on species which have characteristics associated with species that have shown marked declines or have disappeared. Attention has also focused on species with restricted natural ranges, usually those that are habitat specialists. Determining whether the abundance of a species or the number of populations of a species have declined is more difficult than the observation that a species has disappeared.

Historical data from a variety of sources, including scientific literature, survey reports and museum records, enable a picture to be constructed of previous patterns of distribution and abundance for many species (Table 1). Unfortunately there were few detailed studies of frog populations in Australia prior to 1990. Examination of the titles of some 470 theses relating to herpetology in Australia (Shea 1993), reveals that less than five have dealt with frog community studies. A small number of these do however, provide an invaluable source of information on population dynamics (Dankers 1978; Humphries 1979; Cappo 1986; Lemckert 1991), and these are useful in considering changes in population trends at specific sites. The study of Humphries (1979) on a site in the Southern Tablelands region of New South Wales, for example, is valuable because a population of the Southern Tableland Bell Frog *L. castanea* and the Green and Golden Bell Frog *L. aurea* were known from this site. Visits to the site in recent years have failed to record either species, although all other species recorded in the original study still occur at the site (pers. obs.).

There is now ample evidence from intensive studies in a number of habitats in eastern Australia, to show that over 15 species have declined, and ten have disappeared (Table 2) (Richards *et al.* 1993; Ingram and McDonald 1993; Osborne *et al.* 1996).

A significant point, one that is often misunderstood, is that not all species of frogs found along the east coast of Australia are in decline; for many species their populations apparently remain robust and their distribution undiminished. The focus in the media and popular scientific journals on "global declines among amphibians" has led to the impression among many that all species of amphibians are in decline. This is clearly not the case. Empirical evidence from surveys in a variety of habitats reveals that many species can be found in apparently normal abundance in suitable sites throughout their known range. This assessment is based on extensive field surveys in the past four years (M. Mahony, unpubl. data), and the results of studies in specific regions such as the North East Forest Biodiversity Study undertaken by the NSW National Parks and Wildlife Service. Of numerous examples which could be cited, most evident would be pond breeding species such as *Litoria latopalmata, L. freycineti, L. peroni, Crinia signifera, Limnodynastes peroni, Lim. tasmaniensis* and *Uperoleia laevigata*. These species can be found in a variety of situations ranging from natural vegetated areas to those which have been extensively cleared and modified. Populations occur across a range of altitudes. Species that have been reported from sites that cover a reasonable portion of their natural range are listed in Table 1. Although current evidence indicates that these species are not apparently in decline, caution should be exercised and their status regularly monitored. There have been reports of declines and disappearances in some species included here in Table 1, and undoubtedly some of these are real for sections of their range (Ingram and McDonald 1993). In many cases these declines, noted at local levels, can be related to particular deterministic causes, such as habitat destruction or pollution.

Table 1. Ecological characteristics of frogs from the east coast of Australia that have been recorded in a reasonable proportion of their known range in recent surveys. Species that have had declines reported in some populations are marked*.

	Habitat				Altitude	
Family/Genus/Species	Streams	Permanent ponds or swamps	Ephemeral pools	Embryos and/or tadpoles do not rely on standing water	<300 m	>300 m
HYLIDAE						
Litoria alboguttata			X		X	
L. bicolor		X	X		X	
*L. brevipalmata**			X		X	
L. caerulea	X	X			X	
L. chloris		X	X		X	X
L. citropa					X	X
*L. cooloolensis**		X			X	
*L. dentata**		X	X		X	X
L. dorsalis		X	X		X	
L. ewingi		X			X	X
L. fallax		X	X		X	X
L. freycineti		X	X		X	
L. gracilenta		X	X		X	
L. inermis		X	X		X	
L. infrafrenata		X			X	
L. jervisiensis		X	X		X	
L. latopalmata	X	X	X		X	X
L. littlejohni		X	X		X	X
L. longirostris					X	
*L. nasuta**		X	X		X	
L. nigrofrenata	X	X			X	
*L. olongburensis**	X	X			X	
L. peroni	X	X			X	X
MYOBATRACHIDAE						
*Assa darlingtoni**				X		X
Crinia parinsignifera		X	X		X	X
C. remota		X	X		X	X
C. signifera		X	X		X	X
*C. tinnula**		X			X	
Limnodynastes dumerilli		X			X	X
L. fletcheri		X	X		X	
L. ornatus		X	X		X	X
L. peroni		X	X		X	X
L. salmini		X	X		X	
L. terraereginae		X			X	X
L. tasmaniensis		X	X		X	X
Paracrinia haswelli		X	X		X	
*Pseudophryne australis**			X	X	X	
*P. bibroni**		X	X	X	X	X
P. coriacea			X	X	X	X
P. dendyi			X	X	X	X
P. major			X	X	X	
P. raveni			X	X	X	
P. covacevichae			X	X	X	
Geocrinia victoriana		X	X	X	X	X
*Heleioporus australiacus**	X				X	
*Kyarranus kundagungan**				X		X
*K. loveridgei**				X		X
*K. sphagnicolus**				X		X
*Lechriodus fletcheri**			X		X	X
Mixophyes fasciolatus	X			X	X	X
M. schevilli	X			X	X	X
Neobatrachus sudelli		X	X		X	X
Notaden melanoscaphus		X	X		X	
Paracrinia haswelli		X			X	
*Philoria frosti**		X		X		X
Taudactylus liemi	X					X
T. pleinoni	X					X
Uperoleia fusca		X			X	X
U. laevigata		X			X	X
U. lithomoda		X			X	X
U. mimula		X				X
U. rugosa		X			X	
U. tyleri		X			X	X

Table 2. Species of east coast Australian frogs reported to have disappeared or declined. Features of their habitat, behaviour and distribution, considered to be related to declines are indicated. All species that have disappeared occurred at high altitude and were associated with stream habitats. Several other species with the latter characteristics have had populations at high altitude decimated, but low altitude populations appear not to be effected. WFS, wet forest streams; RF, rainforest streams; P, pond.

	Status			Altitude of distribution		Breeding site				
Family/Species	Disappeared	Declined	Habitat	<300 m	>300 m	Stream	Pond	Other (bog, swamp)	Basking behaviour	Ref
MYOBATRACHIDAE										
Adelotus brevis		X	WFS, P	X	X	X	X			1,8
Mixophyes balbus		X	WFS	X	X	X				1,8
M. fleayi		X	WSF	X	X	X				1
M. iteratus		X	WFS	X	X	X				1,8
Philoria frosti		X	Alpine bog		X			X		2
Pseudophryne corroboree		X	Alpine bog		X			X		2
P. bibroni		X	Tableland swamps	X	X			X		1,9
Rheobatrachus silus	X		RF		X	X				3
R. vitellinus	X		RF		X	X				4
Taudactylus acutirostris	X		RF		X	X			X	5
T. diurnus	X		RF		X	X			X	3
T. eungellensis		X	RF		X	X			X	4
T. rheophilus	X		RF		X	X				5
HYLIDAE										
Litoria aurea		X	Still ponds, swamps	X	X	X	X		X	6
L. booroolongensis		X	Streams	X	X		X			1,9
L. castanea	X		Still ponds, swamps		X	X	X		X	2
L. flavipunctata	X		Still ponds, swamps		X	X	X		X	1,9
L. nyakalensis	X		RF		X	X		X		5
L. lesueuri		X	Streams	X	X	X				1
L. lorica	X		RF		X	X		X		5
L. nannotis		X	RF	X	X	X		X		5
L. pearsoniana		X	WFS	X	X	X			?	7
L. piperata	X		Highland streams		X	X			?	1,9
L. spenceri		X	WFS	X	X	X				
L. subglandulosa		X	Highland streams		X	X				1,9
L. rheocola		X	RF	X	X	X		X		5
L. verreauxi alpina		X	Highland streams and ponds		X	X	X	X	?	2
Nyctimystes dayi		X	RF	X	X	X				5

1. Tyler (1994); 2. Osborne (1989, 1990, this volume); 3. Chezura (1991), Chezura and Ingram (1990), Ingram (1983, 1990); 4. McDonald (1990); 5. Richards *et al.* (1993), Trennery *et al.* (1994), Dennis and Mahony (1994); 6. White (this volume); 7. Ingram and McDonald (1993); 8. Mahony (1993); 9. This work.

Analysis of the broad ecological characteristics of the species that have not apparently declined (Table 1) reveals that they; 1) breed in ponds or ephemeral situations, or 2) have embryonic and tadpoles stages that do not rely on free standing water, or 3) occur in semi-arid habitats, or 4) are species/populations found at low altitudes. These broad characteristics are instructive because they help to focus on the proposed hypotheses posited to explain the declines/ disappearances observed in other species.

Examination of Table 1 reveals that 30 of the 43 hylid frogs that have not declined breed primarily in still-water habitats. For an introduction to the breeding ecology and preferred habitat of these species see Tyler (1989). All 15 species of microhylid have direct development, and in four species from two myobatrachid genera (*Assa, Philoria*) tadpoles do not rely on free standing water. A number of species are classified as occupying semi-arid habitats in the area. These species typically are burrowing frogs that breed in permanent or ephemeral pools, and they occur principally in the dry savannah woodlands on the mid east coast of Queensland, they include two species of *Cyclorana*, one *Notaden*, three of *Limnodynastes*, and one species of *Neobatrachus* which occurs on the Northern and Southern Tablelands of New South Wales.

A Review of Frog Declines in Australia

In the search for characteristics which link the species that have declined/disappeared among

Table 3. Comparison of the habitat of adults and larvae of species that, (a) have declined/disappeared, (b) have not disappeared. The number of species are derived from Tables 1 and 2.

	Habitat association of adults[a]		Habitat association of embryos and larvae		Altitude[b]	
Family	Stream	Non-stream habitats; permanent and ephemeral pools, swamps and bogs[d]	Stream	Embryos and larvae in ponds, or not reliant on free standing water	<300 m	>300 m
(a) Number of species that have declined or disappeared						
Myobatrachidae	12	3	10	2	5	12
Hylidae	14	4	14		7	14
TOTAL	26	7	24	2	12	26
(b) Number of species that have not disappeared						
Myobatrachidae	6	38	6	38	30	27
Hylidae	9	26	9		18	11
Microhylidae		15[c]		15	1	15
Ranidae	1		1		1	1
TOTAL	16	79	16	53	50	54

[a] Some species are included in both categories because they are known to breed in ponds, and in slow flowing sections of streams.

[b] Where a species occurs across the range in altitude it has been included in the total for each column.

[c] Adults are associated with rainforest habitats, and not with any particular type of water body.

[d] Includes reproductive behaviour such as direct development, terrestrial egg deposition and parental care.

Australian frogs, attention has been drawn to the geographical, biological and historical pattern of these declines (Richards *et al.* 1993; Laurance *et al.*, in press). The major characteristics as they relate to the ecology and distribution of these species are presented in Table 2. A summarized comparison of the attributes of the species that have declined/disappeared with those that have not, are presented in Table 3.

Several conclusions can be drawn from the information in these tables and from the broader literature on declines/disappearances among Australian frogs:

1. Declines/disappearances were first noticed in the early 1980s.
2. Declines/disappearances have primarily occurred on the east coast and adjacent ranges.
3. There appears to be no particular phylogenetic pattern in these declines.
4. Declines occur precipitously.
5. Among the species that have declined/disappeared most are stream dwelling or breeding species.
6. There is an apparent relationship between altitude and population declines.
7. Introduced predators (e.g., fish) have not been implicated in most cases.
8. Obvious signs of habitat destruction, presence of herbicides, pesticides or other pollutants have not been identified.

Each of these conclusions will be addressed briefly.

1. Declines/disappearances were first noticed in the early 1980s.

Prior to the early 1980s no Australian frog was known to have gone extinct in the previous two hundred years. Recognition was given to the fact that urbanization, clearing of land, and alterations of waterways had impacted on the natural distribution of some species in identifiable situations (Tyler 1991), but no species was considered to be in such a situation where its continued survival was threatened (McDonald 1992). Tyler (1991) has reviewed the historical perspective of the phenomena of declining frogs in Australia. The first significant observations that frog populations were in decline were noted when the Gastric Brooding Frog *Rheobatrachus silus* disappeared in 1980. The first reports of the decline of the Green and Golden Bell Frog are not mentioned in the literature until the early 1990s (see Cogger *et al.* 1993, for a review), but its decline was noted before this time by field herpetologists (Mahony 1991). Evidence from literature and museum records indicate that during the early 1970s the Southern and Northern Tableland species of bell frogs were reasonably abundant (Courtice and Grigg 1975; Humphries 1979; see Thompson *et al.* 1996 and Osborne *et al.* 1996). Sometime in the period between 1975 and 1980 declines apparently occurred in the Northern and Southern Tableland populations of bell frogs (Osborne 1990; Osborne *et al.* 1996).

If the declines were due to deteriorating habitat quality associated with land clearing, the expected pattern would be for animals to disappear from impacted areas and remain in less impacted ones. A gradual rather than sudden decline would be predicted. Furthermore, it is difficult to imagine that the accumulated impacts of anthropogenic changes could be responsible when these regions had long histories of agricultural activities, and natural areas remained within both regions.

2. Declines/disappearances have primarily occurred on the east coast and adjacent ranges

In other regions of the continent some species are known to have narrow natural ranges, however, there is no evidence that these are due to recent declines. In the south west of Western Australia two species of *Geocrinia* (*G. alba*, *G. vitellina*) have very restricted distributions, and it is evident that the natural habitat of these species have been reduced and modified by the impact of anthropogenic changes (Roberts *et al.* 1993). These reductions in range are examples of a deterministic cause, habitat destruction or modification, not a decline from an unknown cause(s). Similarly, there are no reported declines in the range or abundance of any species in the north or north-west of the continent, among the frog faunas of the Kimberley or Arnhem Land regions. Although there are few reports to indicate whether appropriate monitoring to detect any changes in these regions is in place. Three species of the "bell frog group" occur outside the east coast area, *L. cyclorhyncha*, and *L. moorei* in the south west of Western Australia, and *L. dahlii* in the north of the Northern Territory. There have been no reported declines in these species.

3. There appears to be no particular phylogenetic pattern in these declines

Declines/disappearances have been reported among species of two different families, the Myobatrachidae and Hylidae (Table 2), but not among species of the Microhylidae or Ranidae. Even at lower taxonomic levels there is no strong evidence that the cause of the declines/disappearances is related to phylogeny; closely related species have disappeared (e.g., both species of *Rheobatrachus*), but in other cases congeners occurring sympatrically have shown different responses to the unknown cause(s) (e.g., three of the six species of the genus *Taudactylus* have disappeared and three species remain, one in greatly reduced numbers and the other two apparently unaffected) (see Table 2) (Covacevich *et al.* 1982 ; Chezura 1986a, 1986b; Ingram 1990, 1993). The most intriguing situation occurs at Eungella in mid-east Queensland (see Fig. 1), where *T. eungellensis* and *T. liemi* occurred sympatrically, the former species declined markedly in 1986 (McDonald 1990), while the latter appears to remain unaffected (Couper 1993; Covacevich and McDonald 1993; Ingram and McDonald 1993). Although occurring along the same watercourses there is evidence that these species have distinct microhabitat preferences (pers. obs.).

Closer examination of the situation reveals that the connection is more likely to be with a habitat component, physiological attribute or specific life history parameter (see Table 2). It seems likely that because congeners are usually adapted to similar habitats with similar physiology and life history traits, they are likely to be impacted by a perturbation related to that environment or habitat.

4. Declines occur precipitously

Initially declines occurred almost unnoticed, implying that either they were rapid or biological monitoring was insufficient to record a gradual decline over time. The following two examples relating to my own field experience plus the published accounts of several others, support the proposal that the declines occurred rapidly. In 1984 a species of Gastric Brooding Frog *Rheobatrachus vitellinus* was discovered along streams in the Clarke Range west of Mackay in mid-eastern Queensland (Mahony *et al.* 1984), some three years after the time that the Southern Gastric Brooding Frog (*R. silus*) had disappeared from the Conondale Ranges (Fig. 1). By the spring of 1986 this second species had also disappeared, along with the sympatric Eungella Day Frog *Taudactylus eungellensis* (McDonald 1990). Despite extensive and intensive searches, this species has not been sighted since that date, however, the Eungella day frog has reappeared at a number of sites where it was formerly known but in reduced abundance (Couper 1993; J-M. Hero, pers. comm.). Field work indicates that the population of both species crashed precipitously sometime after the spring and summer of 1985 (McDonald 1990). The Gastric Brooding Frog was recorded from three of the creek systems that drain Mt Dalrymple, and it disappeared from each of these. The Eungella day frog used these same streams, it was easy to observe because of its diurnal behaviour and relative abundance, so its decline was readily apparent.

The second case involves the decline of the Sharp-snouted Day Frog *T. acutirostris* from the wet tropics biogeographic region in north Queensland (Fig. 1). In the spring of 1993 while studying the last known population of this species in the north of its former range, sick and moribund frogs of two sympatric stream breeding tree frogs were observed along the stream. Within a period of three months the adult populations of these Tree Frogs and the Sharp-snouted Day Frog had declined markedly, tadpoles remained in the stream for some months but most juveniles died apparently shortly after metamorphosis (Dennis and Mahony 1994).

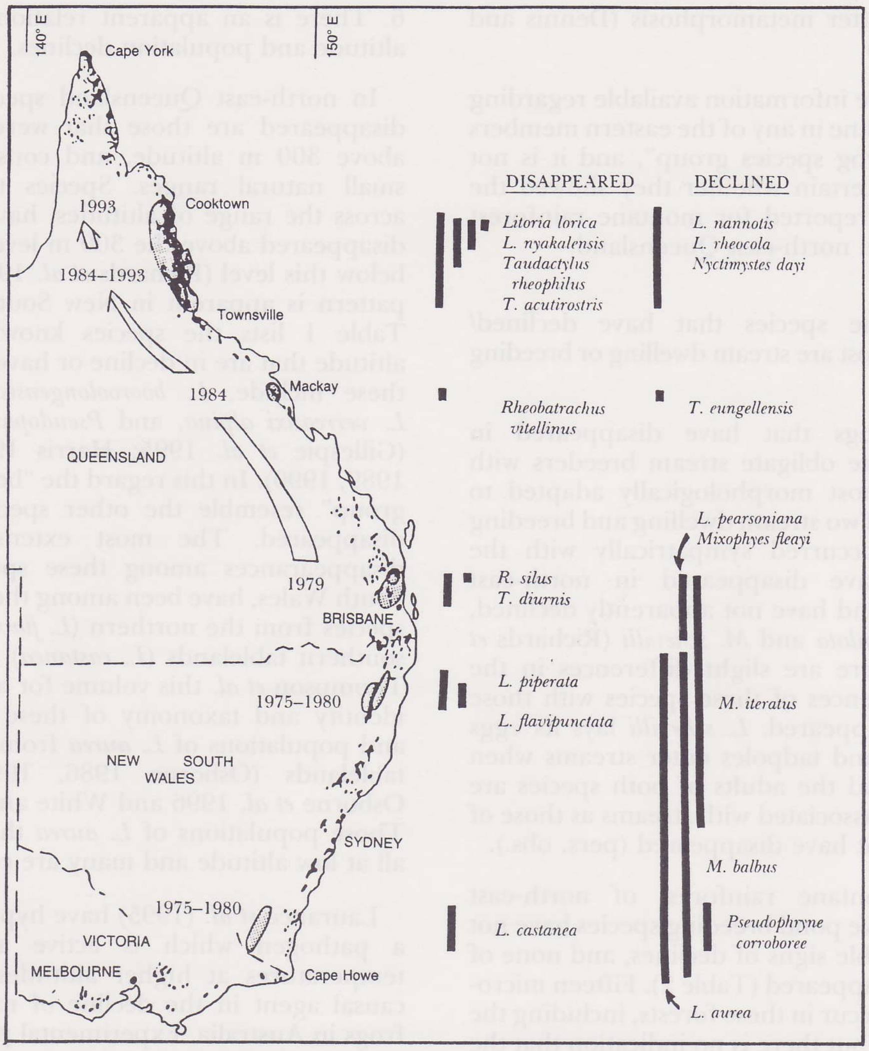

Fig. 1. The distribution of species which have disappeared or declined markedly, from the east coast region of New South Wales and Queensland, shown relative to the distribution of rainforest (aften Werren 1985). Most species which have disappeared were found only at high altitude, whereas those which have declined have populations also at lower altitudes. The historical pattern of decline is indicated. Dates of declines are based on reports in the references to Table 2.

Rapid declines such as those discussed above are not what would be predicted by a number of the "causal agents" that have been put forward to explain frog declines on a global scale. Hypotheses such as increases in harmful Ultraviolet-B irradiation (UV-B) (Blaustein *et al.* 1994), or atmospheric dispersal of stable synthetic chemicals which interfere with the normal hormonal control of physiological functions (Stebbins 1993), would presumably produce gradual declines in abundance. This does not accord with the observations of rapid declines among montane frogs in Australia (Dennis and Mahony 1994). If the second hypothesis were responsible we might expect to see a failure of reproduction. Several of the moribund frogs observed in north Queensland were mature and displayed secondary sexual characteristics; nuptial pads in males and large ovarian follicles in females. Secondly, larvae would be expected to disappear prior to adults. The opposite pattern was observed. Similarly, harmful UV-B might be expected to impact on eggs causing death (see Blaustein *et al.* 1994), however, most of the montane rainforest species that have disappeared, place their eggs beneath rocks, logs or banks, in situations that are not exposed to sunlight (Richards *et al.* 1993). The possibility that increases in UV-B were responsible for the death of juveniles and adults, mediated via depressed immunity, does not agree with two observations. Animals removed from stream habitats and maintained at high altitude in an outdoor pond, survived for several months longer than animals in stream habitats. Larvae collected from the wild and transferred to indoor enclosures at low altitude, either failed to thrive and died, or thrived, but in most cases died shortly after metamorphosis (Dennis and Mahony 1994).

There is little information available regarding the rate of decline in any of the eastern members of the "bell frog species group", and it is not possible to ascertain whether they showed the same pattern reported for montane rainforest stream frogs in north-east Queensland.

5. Among the species that have declined/ disappeared most are stream dwelling or breeding species

All the frogs that have disappeared in Queensland are obligate stream breeders with tadpoles of most morphologically adapted to lotic habitats. Two stream dwelling and breeding species that occurred sympatrically with the frogs that have disappeared in north-east Queensland, and have not apparently declined, are *L. genimaculata* and *M. schevilli* (Richards *et al.* 1993). There are slight differences in the habitat preferences of these species with those that have disappeared. *L. schevilli* lays its eggs out of water and tadpoles enter streams when they hatch, and the adults of both species are not so closely associated with streams as those of the species that have disappeared (pers. obs.).

In the montane rainforest of north-east Queensland five pond breeding species have not shown detectable signs of declines, and none of these have disappeared (Table 2). Fifteen microhylid species occur in these forests, including the riparian zone, but there is no indication that the populations or distributions of these species have declined. These species do not rely on bodies of water for reproduction. Embryonic development and larval life occurs within the egg capsule. Eggs of the various species are laid under rocks or debris on the rainforest floor, in the axils of palms or on vegetation (pers. obs.). A question remains whether monitoring has been suitable to detect declines in these species.

Outside of rainforest habitats along the east coast, many species that breed in permanent ponds or swamps, in ephemeral situations, or have development that is free of standing water, show no sign of declines in populations or distributions (see Table 2). These species require regular monitoring to confirm that their status remains secure.

Members of the "bell frog species group" in eastern Australia (*L. aurea, L. castanea, L. flavipunctata* and *L. raniformis*) are generally not stream dwelling. In some instances they occur in stream habitats (Courtice and Grigg 1975; Pyke and White 1996), but these are usually at sites where large pools, and slow flow, occur.

6. There is an apparent relationship between altitude and population declines.

In north-east Queensland species that have disappeared are those that were once found above 300 m altitude, and consequently had small natural ranges. Species that occurred across the range of altitudes, have declined or disappeared above the 300 m level, but remain below this level (Richards *et al.* 1993). A similar pattern is apparent in New South Wales, and Table 1 lists the species known from high altitude that are in decline or have disappeared, these include, *L. booroolongensis, L. piperata, L. verreauxi alpina,* and *Pseudophryne corroboree* (Gillespie *et al.* 1995; Harris 1995; Osborne 1989, 1990). In this regard the "bell frog species group" resemble the other species that have disappeared. The most extensive declines/ disappearances among these species in New South Wales, have been among the high altitude species from the northern (*L. flavipunctata*) and southern tablelands (*L. castanea*) (see paper by Thompson *et al.* this volume for a discussion of identity and taxonomy of these populations), and populations of *L. aurea* from the southern tablelands (Osborne 1986, 1990; see also Osborne *et al.* 1996 and White and Pyke 1996). Those populations of *L. aurea* that remain are all at low altitude and many are coastal.

Laurance *et al.* (1995) have hypothesized that a pathogen which is active at the cooler temperatures at higher altitudes may be the causal agent in the decline of many montane frogs in Australia. Experimental procedures are necessary to confirm this hypothesis, and the putative pathogen has yet to be identified, isolated, and its origin identified.

7. In most cases introduced predators (e.g., fish) have not been implicated

In all the cases where montane rainforest frogs have declined/disappeared introduced fish do not occur in the streams. At high altitude in the wet tropics biogeographic region where two species of *Taudactylus* and two species of *Litoria* have disappeared, native or introduced fish do not occur in the streams. In the same region two species of *Litoria* and one species of *Nyctimystes* have disappeared at high altitude but remain at low altitude (<300 m), where several species of native fish occur (Hero and Fickling 1995). At Eungella and the Conondale Ranges there are no reports of introduced fish, at both locations the native Long-finned eel (*Anguilla reinhardtii*) is present in the streams. Declines among species of *Pseudophryne* on the southern and northern Tablelands of New South Wales have not been linked with the presence of fish (Osborne 1989).

The situation with the members of the "bell frog species group" in New South Wales is somewhat different to those of the other declining frogs. Native and introduce fish occur in many of the water bodies where populations occurred. On the northern tablelands introduced Mosquito Fish, European Carp, and trout are found in many streams, while the first is also found in many dams and swamps. For example the Mosquito Fish is established in Llangothlin Lagoon and Booroolong Creek, two former sites for the Northern Tablelands Bell Frog (Harris 1995). While the role of Mosquito Fish in the decline of the Green and Golden Bell Frog remains a matter of conjecture, it should be borne in mind that the introduction of this or other predatory fish do not explain, at least by direct predation, the declines in other native frogs discussed above.

8. Obvious signs of habitat destruction, presence of herbicides, pesticides or other pollutants, have not been identified.

One of the most perplexing features of the declines in montane rainforest habitats is the pristine nature of these habitats (Richards *et al.* 1993). Once again this is not entirely the case for the bell frogs. Many sites are in modified habitats including agricultural, urban and industrial lands. Evidence suggests that for *L. aurea* at least, modified habitats do not particularly effect the species. The largest known population in the Sydney region occurs in a disused brick quarry (Greer 1994).

Other Significant Observations: Tadpoles Survive, Juveniles Die.

Post-metamorphic death syndrome was reported by Scott (1993) for several declining high altitude species in north America. This pattern has also been observed in the montane rainforest species that have declined in Australia, with the exception that adults are also susceptible to the causal agent. In several cases tadpoles have been observed in streams after adults and juveniles can no longer be found (Richards *et al.* 1993). Tadpoles of *Taudactylus acutirostris* could be observed in the stream up to four months after the last adults or juveniles had disappeared, and it was usually shortly after metamorphosis that captive held individuals died (Dennis and Mahony 1994). The fate of juveniles in the wild could not be followed because of their small size and the complex nature of the habitat.

The "Bell Frog Species Group" in New South Wales: (Litoria aurea, L. castanea, L. raniformis)

The taxonomy of the various populations of this species group in New South Wales have been considered by other papers in this volume (see Thompson *et al.* 1996). The populations that occurred on the Southern Tablelands (= *L. castanea* southern form, *L. raniformis* and *L. aurea*), and the northern tablelands (= *L. castanea* northern form) have both declined/disappeared (Osborne 1990; Osborne *et al.* 1996; Mahony 1994). The mostly low altitude and eastern coastal species, *L. aurea*, has declined significantly across its range (see White and Pyke 1996), while the status of the fourth species, *L. raniformis*, has not been extensively investigated. Apparently high altitude populations of this latter species have declined (Osborne 1990; Osborne *et al.* 1996) but populations along some western flowing rivers of New South Wales (H. Ehmann, pers. comm.) and along the lower Murray River valley in South Australia contain large numbers (pers. obs.).

The biological features of this "species group" are different to most of those of the species which have declined/disappeared in Queensland. Bell frogs do not occur in montane rainforest, and although they may breed in streams, such sites are usually at pools which are slow flowing. They are more commonly found to breed in still bodies of water, such as swamps and dams. High altitude is a feature that links the New South Wales tableland populations with the Queensland species that have declined, and also provides a link with the other high altitude species or populations of species that have declined in New South Wales and Victoria, such as, *L. booroloongensis*, *L. piperata*, *L. verreauxi alpina*, *Philoria frosti*, *Pseudophryne corroboree*, and *P. bibroni*. None of this group of species occurs in rainforest, and the latter three species do not occupy stream habitats.

Little information was recorded about the speed of the decline in the tableland populations of bell frogs. Perhaps because the time of their decline coincided with a drought in these regions (Osborne 1990) the extent of the situation was not noticed until the animals could not be found. The available evidence indicates that declines occurred on the southern (Osborne 1990), and northern (Mahony 1994) tablelands between 1975 and 1980, shortly before that of the first reported declines of montane rainforest stream species in the Conondale Ranges in south-east Queensland.

Similarities between *L. aurea* and the montane rainforest frogs are even harder to find. *Aurea* is the only species with an extensive lowland distribution that has shown a noticeable decline.

Need for a Pro-active Experimental Research Approach

Whatever the cause of the declines in these frogs, there is a clear need for scientific research to identify the causal agent. To date, most emphasis has been placed on field monitoring.

While this is important in order to identify which species are susceptible and any common trends, and to set in place conservation programmes, without identification of the cause of declines it is not possible to establish strategies to counter its impacts. Emphasis needs also to be placed on an experimental approach to this problem. The animals themselves are the sensitive end-point, it is they which offer the most direct means of ascertaining the causal agent. This approach has been hampered because captive husbandry methods have not been developed for the rainforest species. The successful captive husbandry and breeding of *L. aurea* (W. Meikle, pers. comm.) potentially make it a most useful laboratory model for testing the various hypothesized causal agents of declines.

The above background on the other Australian frogs which have disappeared or are in decline, reveals that the most likely causes are not related to habitat destruction, pollution, climate change, and/or the introduction of predators. The common feature among most species and populations that have disappeared/declined is high altitude. These patterns should be kept in mind when planning for the research and conservation management of the Green and Golden Bell Frog.

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